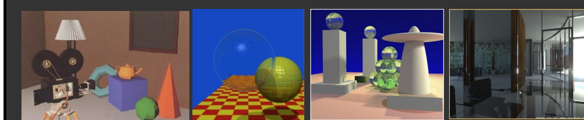
Computer Graphics II: Rendering

CSE 168 [Spr 26], Lectures 18/19: Real-Time Rendering
Ravi Ramamoorthi

http://viscomp.ucsd.edu/classes/cse168/sp26



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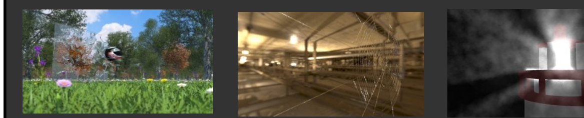
Motivation

- Today, create photorealistic computer graphics
  - Complex geometry, lighting, materials, shadows
  - Computer-generated movies/special effects (difficult or impossible to tell real from rendered…)



  - CSE 168 images from rendering competition (2011)
- ***But algorithms were very slow (hours to days)***

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Real-Time Rendering

- Goal: interactive rendering. Critical in many apps
  - Games, visualization, computer-aided design, …
- Until 20-25 years ago, focus on complex geometry

- ***Chasm between interactivity, realism***

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Evolution of 3D graphics rendering

Interactive 3D graphics pipeline as in OpenGL
- Earliest SGI machines (Clark 82) to today
- Most of focus on more geometry, texture mapping
- Some tweaks for realism (shadow mapping, accum. buffer)

SGI Reality Engine 93
(Kurt Akeley)

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Offline 3D Graphics Rendering

Ray tracing, radiosity, photon mapping
- High realism (global illum, shadows, refraction, lighting,..)
- But historically very slow techniques

"So, while you and your children's children are waiting for ray tracing to take over the world, what do you do in the meantime?" Real-Time Rendering

Pictures courtesy Henrik Wann Jensen

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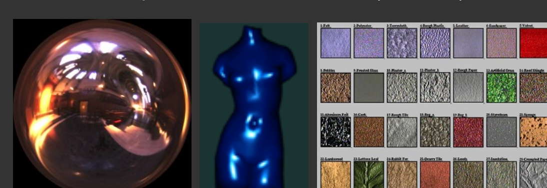
New Trend: Acquired Data

- Image-Based Rendering: Real/precomputed images as input
- Also, acquire geometry, lighting, materials from real world
- Easy to obtain or precompute lots of high quality data. But how do we represent and reuse this for (real-time) rendering?



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25 years ago

- High quality rendering: ray tracing, global illumination
  - Little change in CSE 168 syllabus, from 2003 to today
- Real-Time rendering: Interactive 3D geometry with simple texture mapping, fake shadows (OpenGL, DirectX)
- Complex environment lighting, real materials (velvet, satin, paints), soft shadows, caustics often omitted in both
- *Realism, interactivity at cross purposes*

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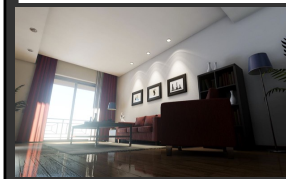
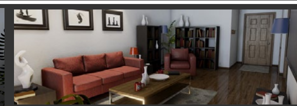
Today: Real-Time Game Renderings





Unreal Engine 4

Digital Ira: NVIDIA, USC

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Today

- Vast increase in CPU power, modern instrs (SSE, Multi-Core)
  - Real-time raytracing techniques are possible (even on hardware: NVIDIA OptiX, RTX Raytracing)
- 4th generation of graphics hardware is *programmable*
  - (First 3 gens were wireframe, shaded, textured)
  - Modern NVIDIA, ATI cards allow vertex, fragment shaders
- Great deal of current work on acquiring and rendering with realistic lighting, materials… [Especially at UCSD]
- *Focus on quality of rendering, not quantity of polygons, texture*

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Goals

- Overview of basic techniques for high-quality real-time rendering
- Survey of important concepts and ideas, but do not go into details of writing code
- Some pointers to resources, others on web
- One possibility for final project, will need to think about some ideas on your own

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To Do

- Final Projects due Jun 9
- PLEASE FILL OUT SET EVALUATIONS!!
- KEEP WORKING HARD

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Outline

- *Motivation and Demos*
- Shadow Maps
- Environment Mapping
- ReSTIR (briefly)

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High quality real-time rendering

- Photorealism, not just more polygons
- Natural lighting, materials, shadows


Interiors by architect Frank Gehry. Note rich lighting, ranging from localized sources to reflections off vast sheets of glass.

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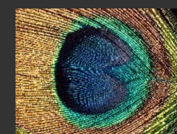
High quality real-time rendering

- Photorealism, not just more polygons
- Natural lighting, materials, shadows

Glass Vase

Glass Star (courtesy Intel)



Peacock feather

Real materials diverse and not easy to represent by simple parameteric models. Want to support measured reflectance.

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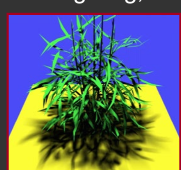
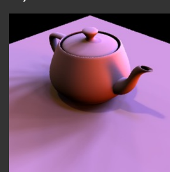
High quality real-time rendering

- Photorealism, not just more polygons
- Natural lighting, materials, shadows



small area light, sharp shadows
Agrawala et al. 00



soft and hard shadows
Ng et al. 03

Natural lighting creates a mix of soft diffuse and hard shadows.

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Today: Full Global Illumination

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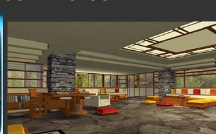
Applications

- Entertainment: Lighting design
- Architectural visualization
- Material design: Automobile industry
- Realistic Video games
- Electronic commerce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Programmable Graphics Hardware

NVIDIA a new dawn demo (may need to type URL)

- https://www.youtube.com/watch?v=bl1_quVr_3w

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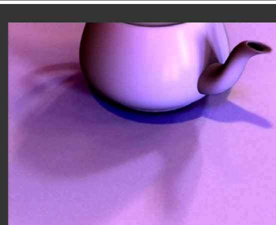
Precomputation-Based Methods

- Static geometry
- Precomputation
- Real-Time Rendering (relight all-frequency effects)
- Involves sophisticated representations, algorithms



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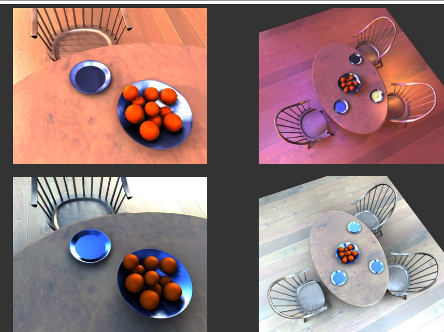
Relit Images



Ng, Ramamoorthi, Hanrahan 04

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Video: Real Time Relighting

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Spherical Harmonic Lighting

Avatar 2010, based on Ramamoorthi and Hanrahan 01, Sloan 02

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Interactive RayTracing

Advantages

- Very complex scenes relatively easy (hierarchical bbox)
- Complex materials and shading for free
- Easy to add global illumination, specularities etc.

Disadvantages

- Hard to access data in memory-coherent way
- Many samples for complex lighting and materials
- Global illumination possible but expensive

Modern developments: Leverage power of modern CPUs, develop cache-aware, parallel implementations

Recent developments make real-time raytracing mainstream (NVIDIA OptiX 5 in 2017, RTX chips in 2018, denoise, DLSS)

https://www.youtube.com/watch?v=kcP1NzB49zU

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NVIDIA RTX Real-Time RayTracing

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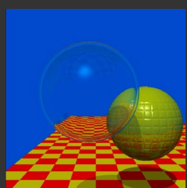
Impact: Real-Time

- Extend AAF, FSF, MAAF: Predict Filter based on Deep Learning (sample and AI-based denoising)
- NVIDIA software (OptiX 2017), hardware (RTX 2018)
- 40-year journey: ray tracing curiosity to every pixel



Whitted 79 (74 min 512x512)

NVIDIA RTX 2018, OptiX: Pixar real-time previewer

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From SIGGRAPH 18

Real Photo: Speaker and Turner Whitted at SIGGRAPH 18

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Outline

- Motivation and Demos
- *Shadow Maps*
- Environment Mapping
- ReSTIR (briefly)

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Shadow and Environment Maps

- Basic methods to add realism to interactive rendering
- Shadow maps: image-based way hard shadows
  - Very old technique. Originally Williams 78
  - Many recent (and older) extensions
  - Widely used even in software rendering (RenderMan)
  - Simple alternative to raytracing for shadows
- Environment maps: image-based complex lighting
  - Again, very old technique. Blinn and Newell 76
  - Huge amount of recent work (some covered in course)
- Together, give most of realistic effects we want
  - **But cannot be easily combined!!**
  - See Annen 08 [real-time all-frequency shadows dynamic scenes] for one approach: convolution soft shadows

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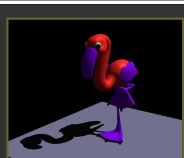
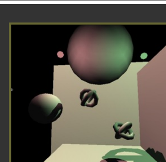
Common Real-time Shadow Techniques



Projected planar shadows



Shadow volumes

Light maps

Hybrid approaches

This slide, others courtesy Mark Kilgard

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Problems

Mostly tricks with lots of limitations

- Projected planar shadows
  works well only on flat surfaces
- Stenciled shadow volumes
  determining the shadow volume is hard work
- Light maps
  totally unsuited for dynamic shadows
- In general, hard to get everything shadowing everything

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Shadow Mapping

- Lance Williams: Brute Force in image space (shadow maps in 1978, but other similar ideas like Z buffer, bump mapping using textures and so on)
- Completely image-space algorithm
  - no knowledge of scene's geometry is required
  - must deal with aliasing artifacts
- Well known software rendering technique
  - Basic shadowing technique for Toy Story, etc.

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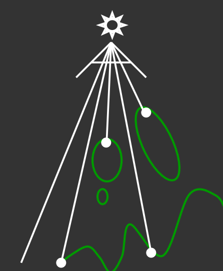
Phase 1: Render from Light

- Depth image from light source



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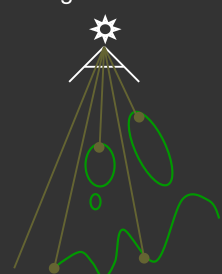
Phase 1: Render from Light

- Depth image from light source



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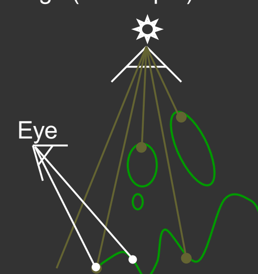
Phase 2: Render from Eye

- Standard image (with depth) from eye



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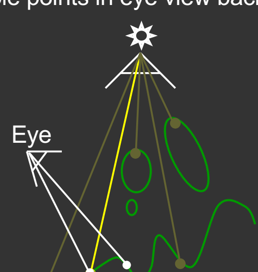
Phase 2+: Project to light for shadows

- Project visible points in eye view back to light source



(Reprojected) depths match for light and eye. VISIBLE

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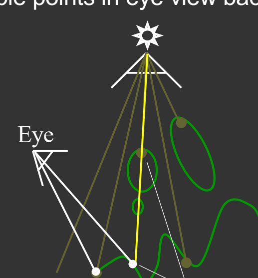
Phase 2+: Project to light for shadows

- Project visible points in eye view back to light source



(Reprojected) depths from light, eye not the same. BLOCKED!!

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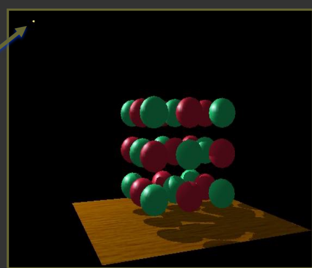
Visualizing Shadow Mapping

- A fairly complex scene with shadows

the point light source



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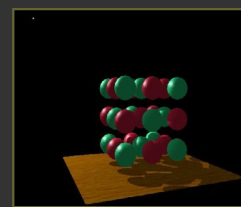
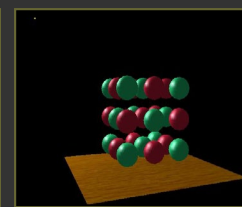
Visualizing Shadow Mapping

- Compare with and without shadows



with shadows



without shadows

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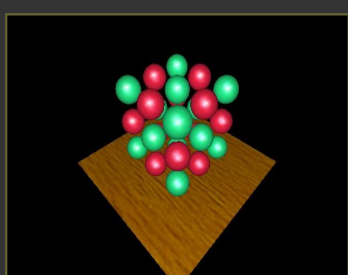
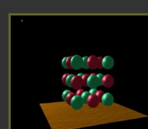
Visualizing Shadow Mapping

- The scene from the light's point-of-view





FYI: from the eye's point-of-view again

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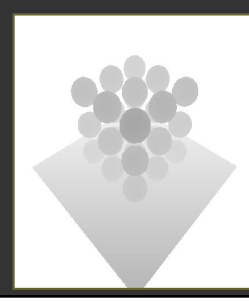
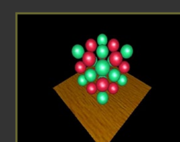
Visualizing Shadow Mapping

- The depth buffer from the light's point-of-view





FYI: from the light's point-of-view again

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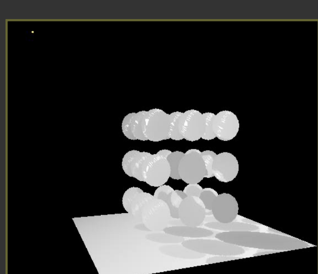
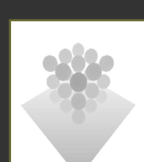
Visualizing Shadow Mapping

- Projecting the depth map onto the eye's view





FYI: depth map for light's point-of-view again

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Visualizing Shadow Mapping

- Comparing light distance to light depth map

Green is where the light planar distance and the light depth map are approximatel y equal

Non-green is where shadows should be

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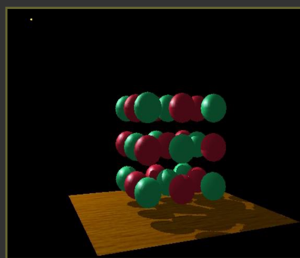
Visualizing Shadow Mapping

- Scene with shadows

Notice how specular highlights never appear in shadows



Notice how curved surfaces cast shadows on each other

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Hardware Shadow Map Filtering

"Percentage Closer" filtering
- Normal texture filtering just averages color components
- Averaging depth values does NOT work
- Solution [Reeves, SIGGRAPH 87]
  - Hardware performs comparison for each sample
  - Then, averages results of comparisons
- Provides anti-aliasing at shadow map edges
  - Not soft shadows in the umbra/penumbra sense

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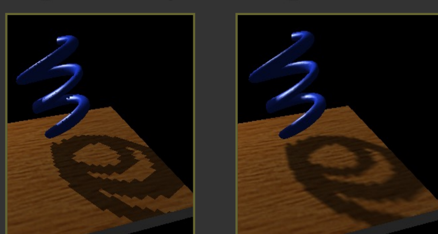
Hardware Shadow Map Filtering

GL_NEAREST: blocky　　*GL_LINEAR: antialiased edges*



Low shadow map resolution used to heighten filtering artifacts

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Problems with shadow maps

- Hard shadows (point lights only)
- Quality depends on shadow map resolution (general problem with image-based techniques)
- Involves equality comparison of floating point depth values means issues of scale, bias, tolerance

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Outline

- Motivation and Demos
- Shadow Maps
- *Environment Mapping*
- ReSTIR (briefly)

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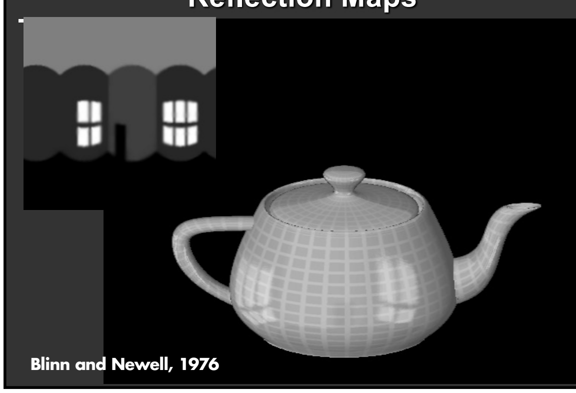
Reflection Maps



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Environment Maps


Miller and Hoffman, 1984

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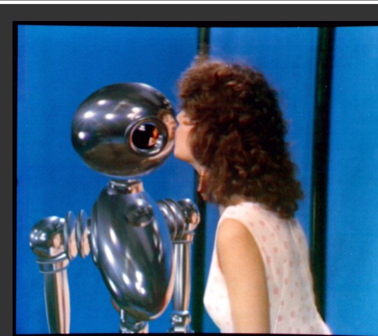
Environment Maps



Interface, Chou and Williams (ca. 1985)

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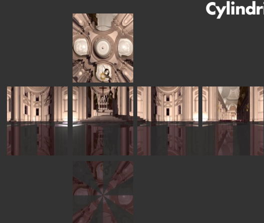
Environment Maps

Cylindrical Panoramas



Cubical Environment Map

180 degree fisheye
Photo by R. Packo

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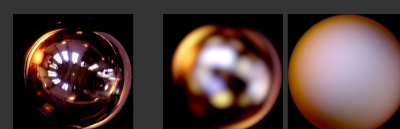
Reflectance Maps

- Reflectance Maps (Index by N)
- Horn, 1977
- Irradiance (N) and Phong (R) Reflection Maps
- Miller and Hoffman, 1984



Mirror Sphere Chrome Sphere Matte Sphere

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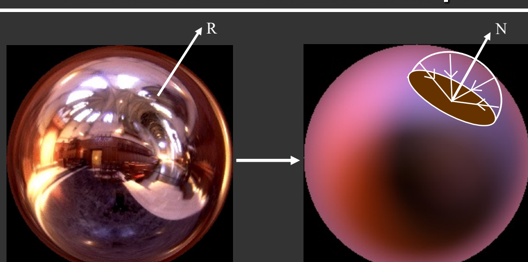
Irradiance Environment Maps



Incident Radiance
(Illumination Environment Map)

Irradiance Environment Map

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Assumptions

- Diffuse surfaces
- Distant illumination
- No shadowing, interreflection

Hence, Irradiance a function of surface normal

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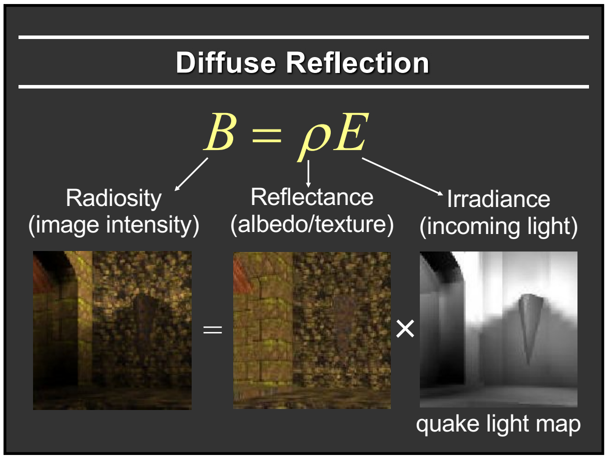

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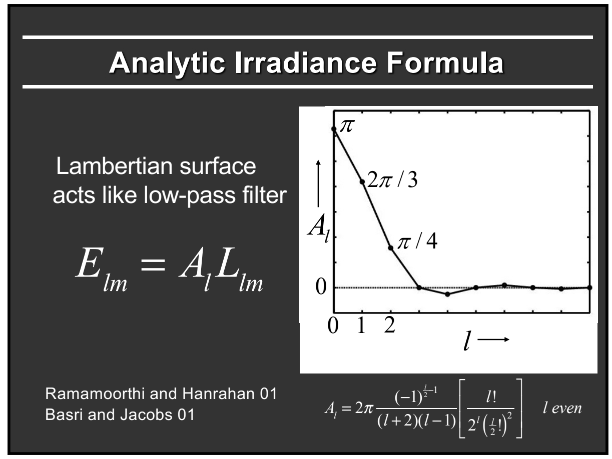

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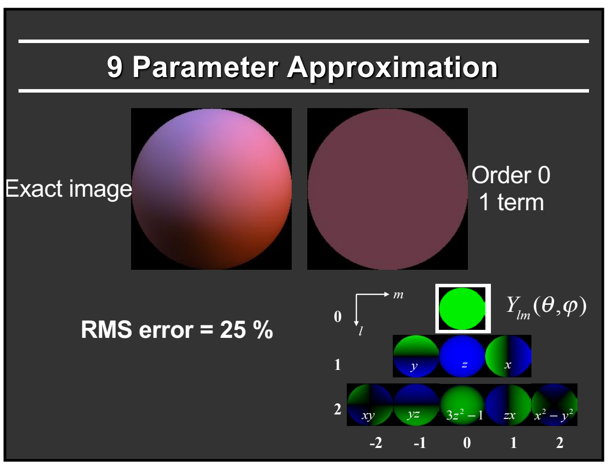

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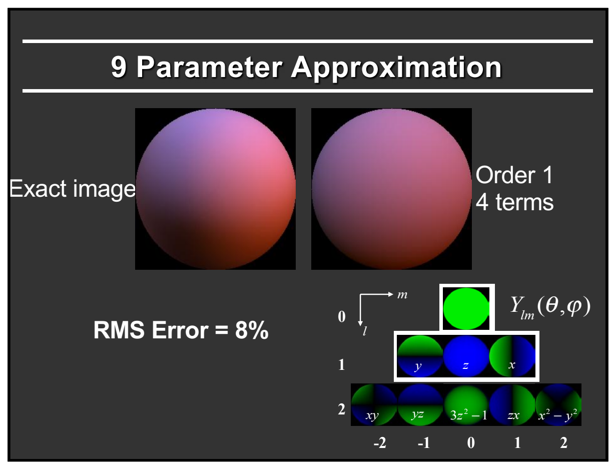

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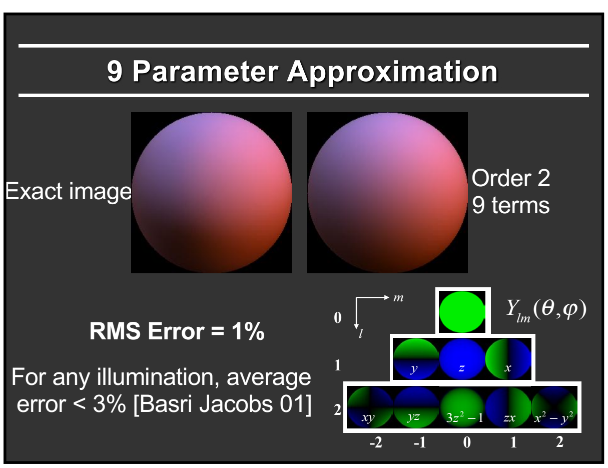

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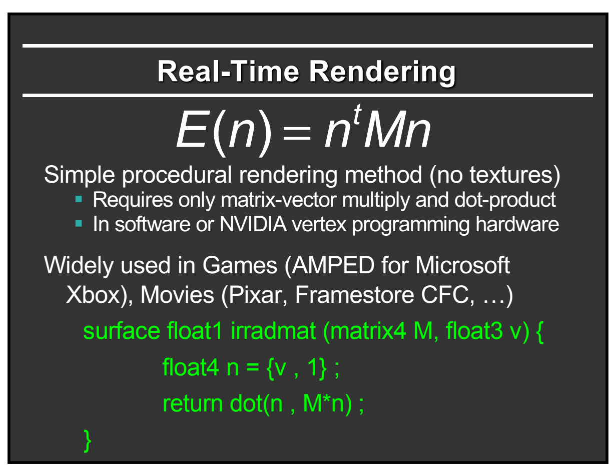

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Environment Map Summary

- Very popular for interactive rendering
- Extensions handle complex materials
- Shadows with precomputed transfer

- But cannot directly combine with shadow maps
- Limited to distant lighting assumption

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Resources

- OpenGL red book (latest includes GLSL)
- Web tutorials: http://www.lighthouse3d.com/tutorials/
- Older books: OpenGL Shading Language book (Rost), The Cg Tutorial, …
- http://www.realtimerendering.com
  - Real-Time Rendering by Moller and Haines
- Debevec http://www.debevec.org/ReflectionMapping/
  - Links to Miller and Hoffman original, Haeberli/Segal
- http://www.cs.ucsd.edu/~ravir/papers/envmap
  - Also papers by Heidrich, Cabral, …
- Lots of information available on web…
- Look at resources from CSE 274 website (Wi, Fa 15)

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